Final Report

LHC Olympics Workshop and String Phenomenology 2006 Conference,
August 7 – December 15, 2006
for the
Department of Energy
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These conferences, *LHC Olympics Workshop* and *String Phenomenology 2006*, took place Thursday August 24 – Friday August 25, 2006 and Monday August 28 – Friday September 1, 2006 at the Kavli Institute for Theoretical Physics and were organized by:

(A) LHC Olympics	(B) String Phenomenology 2006
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String Phenomenology

Final Report of KITP Workshop, August-December 2006

Michael Dine, Shamit Kachru, Gordon Kane, Joe Lykken, Fernando Quevedo and Eva Silverstein

1) Introduction

Particle physics is at the dawn of a new era, as the Large Hadron Collider, the most powerful accelerator ever built, is set to begin operation at the end of 2007. This instrument will probe distances fully an order of magnitude smaller than probed in the past. It is widely expected that dramatic effects, associated with the breaking of the symmetry of the electroweak interactions, will appear at this scale. Candidate phenomena include supersymmetry, new strong interactions, and large or warped extra dimensions; another possibility is simply the Standard model itself (including the Higgs particle). Similarly, the last decade has seen great leaps in our knowledge of the early history of the universe. Inflation as the origin of cosmic structure is now reasonably well established.

Until recently, superstring theory, despite its successes in taming the difficulties of quantum gravity, has proven unable to make definitive predictions for phenomena at accelerators or in the cosmos. Recent developments have raised hopes that this situation is about to change. Previously, one could identify at least three related, major obstacles to any detailed understanding of how string theory was related to nature.

1. There is a vast array of possible string ground states, distinguished, for example, by various topological features.
2. Only those ground states with a unbroken supersymmetry were at all understood quantum mechanically.
3. Among candidate non-supersymmetric states, there were always (pseudo)moduli (scalar fields with potentials which at least asymptotically tend to zero). It seemed that any stable or metastable minima of their potentials would lie in a region where one had no techniques for controlled analysis.
4. String theory seemed to make no useful statements about the observed dark energy. Any plausible estimate suggested a value many, many orders of magnitude too large.

This rather bleak picture has been dramatically altered by the discovery that string theory has a vast array of stable and metastable isolated ground states, with and without supersymmetry, and without moduli. The problem, now, appears to be to develop an understanding of this *landscape* of string vacua. One would like to

1. Characterize and classify the states of this landscape. How many have features consistent with the Standard Model and cosmological observations.
2. All of these vacua contain numerous additional excitations. Some of these are likely to be at energy scales accessible to the LHC; others relevant to early

universe cosmology. Can we classify these possible features, and say which the theory predicts in some definite way?

3. Specifically, does the theory predict warped extra dimensions, supersymmetry, or some other class of phenomena at the TeV scale? From a purely top down perspective, the set of string compactifications include examples with or without low energy supersymmetry, warping, and Technicolor. Each of these possibilities has been developed in interesting regimes of the theory. Whether or not one can say, a priori, that string theory predicts one or more of these phenomena is one of the most important questions in the subject.
4. Again, more specifically: what does the theory have to say about inflationary cosmology? At the level of our current understanding, there are several classes of candidate inflatons, the most dramatic being *colliding branes*. Many of these inflationary mechanisms lead to potentially observable consequences, such as *cosmic strings and non-gaussian corrections to the CMBR.*

Making sense of this picture probably requires understanding of cosmology at a still more fundamental level, facing the challenges of *eternal inflation.* In a landscape picture, it may well be essential to understand just how the universe found its way into the observed vacuum; it could well be that some subset of vacua are strongly favored by such considerations.

While these questions are challenging, this is the first period when answers to interesting phenomenological questions in string theory appear within reach. The goal of the workshop was to pursue these questions, both from a ``top down" perspective in fundamental string theory and from a ``bottom up" perspective, examining clues from present experiments. The hope is that this work will lead to predictions for LHC physics, as well as frameworks in which to interpret results. Similarly, there is the hope of providing a fundamental framework to understand observational results in cosmology and astrophysics.

2) Organization

At any given time, there were approximately 30 participants in the workshop including local ones. Average visits were approximately three weeks. Most of the organizers were resident for longer periods: Quevedo for over a month at the beginning of the workshop; Kachru and Silverstein for the latter three months; Dine for approximately three days each week throughout the workshop, and Kane for the duration of the program. Initially, the organizers experimented with dividing the participants into subgroups, dealing with topics such as cosmology, landscape statistics, new vacuum construction, and the like. One initial group focused on LHC physics and possible connections to underlying string theories. This approach proved cumbersome, however; rather than informal meetings, the groups each became separate seminar series. Instead, we adopted a format with generally one formal and one informal seminar per week, and typically one informal discussion. This, along with the flux of interesting visitors, proved an effective arrangement. Early in the program Kane gave a blackboard talk to participants focused

on the expectations for the experimental program at the LHC. Later Dine gave a talk geared towards explaining recent theoretical developments and the prospects for progress in string phenomenology, as well as the challenges.

Many of the informal discussions were pedagogical in nature. For example, Graham Ross spoke about the quark and lepton mass matrices. Piyush Kumar about LHC physics, Eva Silverstein discussed the space of compactification geometries and topologies. Joe Polchinski introduced the problem of eternal inflation. Shamit Kachru explained theoretical and phenomenological aspects of gravity wave signatures from inflation. Michael Dine lectured on problems of flavor, mainly in the context of models of supersymmetry.

It was decided to hold the conference connected with the workshop towards the beginning, as part of the annual international *String Phenomenology* conference series. This proved an effective way in which to begin the program, with useful talks dealing with all of the issues and developments enumerated above, as well as talks on the application of string theory to QCD and to heavy ion physics (RHICC).

3) Accomplishments

The problems enumerated above are challenging, but progress was made in each area, generally by small collaborations or individuals. In addition, numerous continuing research programs were launched as a result of discussions and seminars held during the workshop.

In the area of model construction, there was a great deal of ongoing work (Cvetic, Raby, Nilles, Kim, Kiritsis). Much of the focus here was on the question of extra chiral matter (*chiral exotics*) which often appear in these constructions. There were also reports and work on the statistical distributions of gauge groups and chiral matter (Taylor, Douglas, Raby). At present, the evidence for interesting correlations among these quantities is not conclusive; this remains the focus of much activity among the participants. Kane and collaborators Kumar and Acharya pursued their study of compactifications with soft supersymmetry breaking and moduli stabilization on G2 manifolds. Several participants (Lykken, Everett, Nelson) participated in in G2 studies, and a number of others had extensive discussions. Kane, Kumar, Acharya, Shao, and Bobkov completed work on the better part of a long paper on these constructions. Acharya discussed this approach during the conference, and Gukov talked about embedding chiral fermions in G2 manifolds.

Soft supersymmetry breaking was studied in IIB string models with flux moduli stabilisation. In particular Crermades and Quevedo finished work (with J. Conlon) in which the Kahler potential for chiral matter fields can be determined in a large Calabi-Yau volume expansion. This was the missing piece in order to properly study soft supersymmetry breaking in these string constructions. Quevedo and collaborators also finished a paper on the explicit form of soft breaking terms on these models addressing

long standing issues, such as universality, from the properties of the Calabi-Yau moduli space. On a different direction some of the participants (de Alwis, Giddings, Maharana, Quevedo) collaborated on a project to study supersymmetry breaking in warped compactifications with moduli fixing. They finished a paper on this subject, where important issues, such as the correct value of the gravitino mass were settled.

Some of the model construction dealt directly with possible observable phenomena in LHC physics. Kane, Kumar, and Shao completed a long paper on these issues. A number of participants showed interest in learning more about how stringy theories might give LHC signatures, and in how LHC observations might suggest high scale physics.

Progress continued on dynamical supersymmetry breaking and its mediation, using both field theoretic and string theoretic methods. Kachru and collaborators developed new models of metastable SUSY breaking in warped throats. Dine, Feng and Silverstein completed their development of a new class of models exhibiting dynamical supersymmetry breaking. These models begin with the observation of early works on dynamical SUSY breaking, early landscape works, and the recent work of Intriligator, Shih and Seiberg , that metastable dynamical supersymmetry breaking provides an interesting approach to model building and the hierarchy problem. Rather than combine the SUSY breaking sector with the sector generating a dynamically small scale, simpler models result from combining classic O'Raifeartaigh models and ``retrofitting" them with dynamical scales from a separate SUSY sector. Dine et al used this to exhibit a much broader class of models. As a result, such metastable supersymmetry breaking now appears to have a much more generic character. Dine continued with work in this direction while at KITP. In related work, he collaborated with Seiberg developing an understanding of the field theory phenomenon of anomaly mediated supersymmetry breaking.

Green, Lawrence, Morrison, Silverstein, Starr (and collaborator McGreevy) developed a new string duality relating two broad classes of string models. The positive tree level potential energy arising in supercritical strings, and in strings on negatively curved compact manifolds, played an important part in early de Sitter constructions following the Bousso-Polchinski work. During the workshop, the above participants solidified a new string duality (proposed by Silverstein during the previous year's Strings/math workshop) relating string theory on compact negatively curved spaces with supercritical strings; the rich topology of one-cycles on the former build up new dimensions. Curved compactifications and extra dimensions being generic, this study is relevant to questions about top-down naturalness of various phenomenological possibilities.

There was a good deal of work on the problem of eternal inflation. Bousso continued his research program on measures of eternal inflation, arguing about the possible role of the inflationary volume and the de Sitter horizon. Shenker reported on a possible vacuum selection effect, involving the lifetime of the preceding state. He and others also assessed and critiqued various measures which have been proposed for eternal inflation. Dine launched a project with Volansky, one of the student affiliates, to determine which classes of landscape states are highly metastable, and reported some preliminary results.

5. Conclusions

The organizers and the participants were very pleased with the program. The atmosphere was quite stimulating, with many points of view about the problems represented. String theorists learned a great deal from phenomenologists, and vice versa. Progress was made on many of the critical questions in the field. The KITP faculty were an important resource throughout the workshop. The staff of the KITP made all stages of the process, from the conference to the day to day management of seminars and visitors an easy matter. Professor Einhorn and Deborah Storm, in particular, kept our focus on important organizational details which were crucial to the success of the program. We believe that the workshop provided a significant positive contribution to progress on these crucial questions in particle physics.

KITP Conference: 3rd LHC Olympic Workshop (Aug 24-25, 2006)
Coordinators: Nima Arkani-Hamed, Gian Guidice, Gordy Kane, Matt Strassler, Herman Verlinde)

Thursday, August 24, 2006

9:00am	Claudio Campagnari (UCSB, CMS)	Searches for New Physics at the LHC: An Experimentalist's Perspective [Slides][Podcast][Aud][Cam]
10:15am	DISCUSSION	
10:30am	MORNING BREAK	
11:00am	John Conway (UC Davis, CMS)	PGS 4 and the LHC Olympics [Slides][Podcast][Aud][Cam]
12:15pm	DISCUSSION	
12:30pm	LUNCH BREAK	
2:00pm	Matt Baumgart (Harvard)	Discovery and Measurement of Sleptons with a Z' [Slides][Podcast][Aud][Cam]
2:30pm	Elena Accomando (INFN)	Analysis on Blackbox A [Podcast][Aud][Cam]
2:50pm	John Conley, Tommer Wizansky (Stanford, SLAC)	Analysis of Blackbox A [Podcast][Aud][Cam]
3:10pm	AFTERNOON BREAK	
4:00pm	Jonathon Walsh (Univ. Washington)	Blackbox A: Analysis, Unveiling, and kT/cone Comparison [Slides][Podcast][Aud][Cam]
5:10pm	Jesse Thaler (UC Berkeley)	Little M-theory [Slides][Podcast][Aud][Cam]
5:45pm	SHUTTLE TO BWSCI	

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Friday, August 25, 2006

9:00am	Zvi Bern (UCLA)	Precision Calculations for the LHC [Slides][Podcast][Aud][Cam]

10:15am	DISCUSSION	
10:30am	MORNING BREAK	
11:00am	Hitoshi Murayama (UC Berkeley)	What Shall We Expect at the LHC?[Podcast][Aud][Cam]
12:15pm	DISCUSSION	
12:30pm	LUNCH BREAK	
2:00pm	Mike Ambroso, Michael Schulz (UPenn)	ChRoot Tools and Preliminary Observations on Blackbox B [Slides][Podcast][Aud][Cam]
2:25pm	Kyle Armour (Univ. Washington)	UWashington Analysis of Blackbox B [Slides][Podcast][Aud][Cam]
2:45pm	QUICK BREAK	
3:00pm	Philip Schuster, Natalia Toro (Harvard)	Towards solving the LHC inverse problem and Box C as an example. [Podcast][Aud][Cam]
4:00pm	Scott Thomas (Rutgers)	Revealing Box B and Box C [Slides][Podcast][Aud][Cam]
4:30pm	AFTERNOON BREAK	
5:00pm	Patrick Meade (Cornell/Harvard)	BSM Event Generation: status, prospects, and a new blackbox. [Slides]
5:45pm	SHUTTLE TO BWSCI	

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KITP Conference: String Phenomenology 2006 (August 28 - September 1, 2006)
Coordinators: Michael Dine, Shamit Kachru, Gordy Kane, Joe Lykken, Fernando Quevedo, Eva Silverstein

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Speakers: Please lend your transparencies to the KITP staff members in the front office (Rm 1102) for scanning, or see us about file upload.

Monday, August 28, 2006

Talks will be 25 minutes with 10 minutes at the end of each talk for questions/discussion.

Morning Session Chair: Michael Dine

9:00am	Martin Einhorn (KITP Deputy Director)	Welcome [Podcast][Aud][Cam]
9:15am	Joe Polchinski (UCSB, KITP)	The Cosmological Constant and the String Landscape [Slides][Podcast][Aud][Cam]
9:50am	Henry Tye (Cornell)	Cosmic Strings: an Update [Slides][Podcast][Aud][Cam]
10:25am	MORNING BREAK	
10:55am	Krishna Rajagopal (MIT)	Probing the Properties of Quark-Gluon Plasma with Experiments and AdS/CFT Calculations [Slides][Podcast][Aud][Cam]
11:30am	Josh Friess (Princeton)	AdS/CFT and the Relativistic Heavy Ion Collider [Slides][Podcast][Aud][Cam]
12:05pm	Rob Myers (Perimeter)	Holographic Phase Transitions with Fundamental Matter [Slides][Podcast][Aud][Cam]
12:40pm	LUNCH BREAK	

Afternoon Session Chair: Sonia Paban

2:15pm	Raphael Bousso (UC Berkeley)	The Entropic Principle [Slides][Podcast][Aud][Cam]

2:50pm	Eva Silverstein (Stanford, SLAC)	Retrofitting O'Raifeartaigh Models with Dynamical Scales [Slides][Podcast][Aud][Cam]
3:25pm	AFTERNOON BREAK	
3:55pm	Angel Uranga (CERN, Switzerland)	IR Dynamics and Supersymmetry Breaking from D-branes at Singularities [Slides][Podcast][Aud][Cam]
4:30pm	Graham Ross (Univ. Oxford)	Racetrack Inflation and Assisted Moduli Stabilization [Podcast][Aud][Cam]
5:05pm	INFORMAL DISCUSSIONS	WINE AND CHEESE RECEPTION
6:30pm	SHUTTLE TO BWSCI	*time is flexible

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Tuesday, August 29, 2006

Talks will be 25 minutes with 10 minutes at the end of each talk for questions/discussion.

Morning Session Chair: Jihn Kim

9:15am	Herman Verlinde (Princeton)	Towards the Standard Model via D-branes at Singularities [Slides][Podcast][Aud][Cam]
9:50am	Burt Ovrut (UPenn)	Heterotic Standard Models, Supersymmetry Breaking and the Cosmological Constant [Slides][Podcast][Aud][Cam]
10:25am	MORNING BREAK	
10:55am	Alon Faraggi (Univ. Liverpool)	Minimal Standard Heterotic String Models [Slides][Podcast][Aud][Cam]
11:30am	Michael Ratz (T.U. München)	Local Grand Unification [Slides][Podcast][Aud][Cam]
12:05pm	Stuart Raby (Ohio State)	Stringy Origin of non-Abelian Discrete Flavor Symmetries [Slides][Podcast][Aud][Cam]
12:40pm	LUNCH BREAK	

Afternoon Session Chair: Mary K. Gaillard

2:15pm	Bobby Acharya (Abdus Salam ICTP)	The LHC and Hierarchies in String/M Theory [Slides][Podcast][Aud][Cam]

2:50pm	Bert Schellekens (NIKHEF)	RCFT Orientifolds and Standard Model Realizations [Slides][Podcast][Aud][Cam]
3:25pm	AFTERNOON BREAK	
3:55pm	Gary Shiu (Univ. Wisconsin)	Brane Inflation: Observational Signatures and Non-Gaussianities [Slides][Podcast][Aud][Cam]
4:30pm	Richard Easther (Yale Univ.)	Observational Constraints on Cosmology: Implications (and Hints) For Model Builders [Podcast][Aud][Cam]
5:05pm	INFORMAL DISCUSSIONS	WINE AND MIXED NUTS
6:00pm	SPECIAL EVENTS DINNER	
8:00pm	SHUTTLE TO BWSCI	*time is flexible

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Wednesday, August 30, 2006

Talks will be 25 minutes with 10 minutes at the end of each talk for questions/discussion.

Morning Session Chair: Elias Kiritsis

9:15am	Tom Banks (Rutgers/Sta Cruz)	Remodeling the Pentagon After The Events of 2/23/06 [Slides][Podcast][Aud][Cam]
9:50am	Nima Arkani-Hamed (Harvard, KITP GM)	On Landscape Phenomenology [Podcast][Aud][Cam]
10:25am	MORNING BREAK	
10:55am	Matt Strassler (Univ. Washington)	Effect of New Gauge Sectors on Tevatron and LHC Phenomenology [Slides][Podcast][Aud][Cam]
11:30am	Steve Giddings (UCSB)	Warped Compactification Phenomenology [Slides][Podcast][Aud][Cam]
12:05pm	Arthur Hebecker (Univ. Heidelberg)	The Ubiquitous Throat [Slides][Podcast][Aud][Cam]
12:40pm	LUNCH BREAK	
2:30pm	FREE AFTERNOON	Shuttle Available to BWSCI *time is flexible

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Thursday, August 31, 2006

Talks will be 25 minutes with 10 minutes at the end of each talk for questions/discussion.

Morning Session Chair: Shanta de Alwis

9:15am	Ignatios Antoniadis (CERN, Switzerland)	Gaugino Masses from String Loops [Slides][Podcast][Aud][Cam]
9:50am	Peter Nilles (Univ. Bonn)	Mirage Mediation [Slides][Podcast][Aud][Cam]
10:25am	MORNING BREAK	
10:55am	Piyush Kumar (Univ. Michigan)	LHC String Phenomenology [Podcast][Aud][Cam]
11:30am	Albion Lawrence (Brandeis)	Non-Geometric Vacua [Slides][Podcast][Aud][Cam]
12:05pm	Jay Wacker (Stanford)	On SUSY Breaking and Cosmology [Podcast][Aud][Cam]
12:40pm	LUNCH BREAK	

Afternoon Session Chair: Gordy Kane

2:15pm	Ralph Blumenhagen (Max-Planck-Physik)	New Heterotic GUT and Standard Model Vacua [Slides][Podcast][Aud][Cam]
2:50pm	Wati Taylor (MIT)	The Landscape of Intersecting Brane Models [Slides][Podcast][Aud][Cam]
3:25pm	AFTERNOON BREAK	
3:55pm	SPECIAL SHORT PRESENTATIONS	
	Brent Nelson	Geometry of MSSM[Slides][Podcast][Aud][Cam]
	Bumseok Kyae	Flipped SU(5) from Z_{12-I} Orbifold with Wilson Line[Slides][Podcast][Aud][Cam]
	Kang-Sin Choi	Unification in Intersecting Brane Models[Slides][Podcast][Aud][Cam]
	Sabine Hossenfelder	The Minimal Length Scale[Slides][Podcast][Aud][Cam]

	Roberto Valandro	Warped Models in String Theory[Slides][Podcast][Aud][Cam]
	Felix Brümmer	The Randall-Sundrum Model in String Theory and Throat Field Mediated SUSY Breaking[Slides][Podcast][Aud][Cam]
5:05pm	INFORMAL DISCUSSIONS	WINE AND MIXED NUTS
6:00pm	SPECIAL EVENTS DINNER	
8:00pm	SHUTTLE TO BWSCI	*time is flexible

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Friday, September 01, 2006

Talks will be 25 minutes with 10 minutes at the end of each talk for questions/discussion.

Morning Session Chair: Keith Dienes

9:15am	Mirjam Cvetic (UPenn)	Couplings for Standard Model and GUT String Constructions [Podcast][Aud][Cam]
9:50am	Fernando Marchesano (Ludwig Max. Univ.)	Coisotropic Model Building [Slides][Podcast][Aud][Cam]
10:25am	MORNING BREAK	
10:55am	Fabio Zwirner (Univ. Padua)	Landscape vs. Swampland: The Power of Local Symmetries [Slides][Podcast][Aud][Cam]
11:30am	Scott Thomas (Rutgers)	Landscape Naturalness [Slides][Podcast][Aud][Cam]
12:05pm	Peter Svrcek (Stanford, SLAC)	Axions and String Theory [Podcast][Aud][Cam]
12:40pm	LUNCH BREAK	

Afternoon Session Chair: Gerardo Aldazabal

2:15pm	Dieter Lüst (Ludwig Max. Univ.)	F- and D-terms from D7-branes [Slides][Podcast][Aud][Cam]
2:50pm	Massimo Bianchi (Università di Roma)	Generalized CS Couplings and One-scattering Amplitudes in D-brane Worlds [Podcast][Aud][Cam]
3:25pm	AFTERNOON BREAK	

3:55pm	Gary Horowitz (UCSB)	Microstates of a Neutral Black Hole [Podcast][Aud][Cam]
4:30pm	Lisa Randall (Harvard)	Braneworld Black Holes [Podcast][Aud][Cam]
5:05pm	CONFERENCE END	Shuttle to BWSCI, also available to SB Airport and SB Airbus Goleta location. *time is flexible

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